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The pre-main sequence star HD 34282: A very short period δ Scuti-type pulsator

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ABSTRACT

HD 34282 has been found to pulsate during a systematic search for short-term photometric variability in Herbig Ae/Be stars with the goal of determining the position and size of the pre-main sequence instability strip. Simultaneous Strömgren photometry is used in the frequency analysis, yielding two frequencies with values of $\nu_1 = 79.5$ and $\nu_2 = 71.3$ c d^{-1}. The light curve with the largest amplitude is that of the u band. This behaviour, which is not common for δ Scuti stars, is explained as pulsation in a high radial order in stars near the blue edge of the instability strip. The main period, with a value of 18.12 min, represents the shortest period observed so far for a δ Scuti-type pulsator. A seismic modelling, including instability predictions and rotation effects, has been attempted. It is found that both main sequence and pre-main sequence models predict modes in the range of 56 to 82 c d^{-1} (between 648 and 949 μHz), corresponding to oscillations of radial order n from 6 to 8. The highest of the observed frequencies only becomes unstable for models of low metallicity, in agreement with results from spectroscopic measurements.

Key words: stars: oscillations – δ Sct – stars: pre-main sequence – stars: individual: HD 34282

1 INTRODUCTION

Pre-main sequence (PMS) stars with masses above 1.5 M$_\odot$ are known as Herbig Ae/Be stars (Herbig 1960; Strom et al. 1972). These stars raise several important questions which still need to be answered. First, their PMS nature needs to be confirmed, as their location in the Hertzsprung-Russell (HR) diagram, clearly above the main sequence (MS) (Strom et al. 1972; van den Ancker et al. 1998), leads to the ambiguity that they could be either PMS or post-MS objects. Once their PMS nature is ascertained, the Herbig Ae/Be stars can be used to constrain the modelling of PMS evolution and to study their coupling with the circumstellar (CS) environment, involving e.g. magnetic processes, accretion/ejection processes, exchanges of angular momentum, etc... The study of the pulsations of these stars represents, therefore, a unique opportunity to answer these questions. Suran et al. (2001) have shown that some non-radial unstable modes are extremely sensitive to the details of internal structure, and make it possible to distinguish pre- from post-MS stars, as well as to constrain the internal rotation.

PMS stars with masses above 1.5 M$_\odot$ are expected to cross the instability strip on their way to the MS, spending typically 5% to 10% of their PMS phases within it (Marconi & Palla 1998). This time is sufficiently long for a significant number of Herbig Ae stars to be present in this strip, and, therefore, to presumably exhibit δ Scuti-type pulsations.

Even though photometric variability induced by variable dust obscuration or magnetic activity is rather high in these stars, the time scales for these high amplitude variations are in principle separated from those of δ Scuti-type pulsations: Keplerian rotation of the CS envelope, presumably responsible for variable dust obscuration, occurs on time scales of months, and the star's rotation, at the origin of the variability due to surface activity, is typically of the order of one to several days, while p-modes in these stars are found with periods of minutes to hours.

The observations secured so far of the pulsational variability in Herbig stars are not sufficient to verify the existence, the width and the location of the instability strip in the HR diagram. It is therefore very important to start a systematic photometric survey of a large number of Herbig stars, in order to study the observational characteristics of the PMS instability strip, and to compare them with theoretical predictions (Marconi & Palla 1998). This survey has

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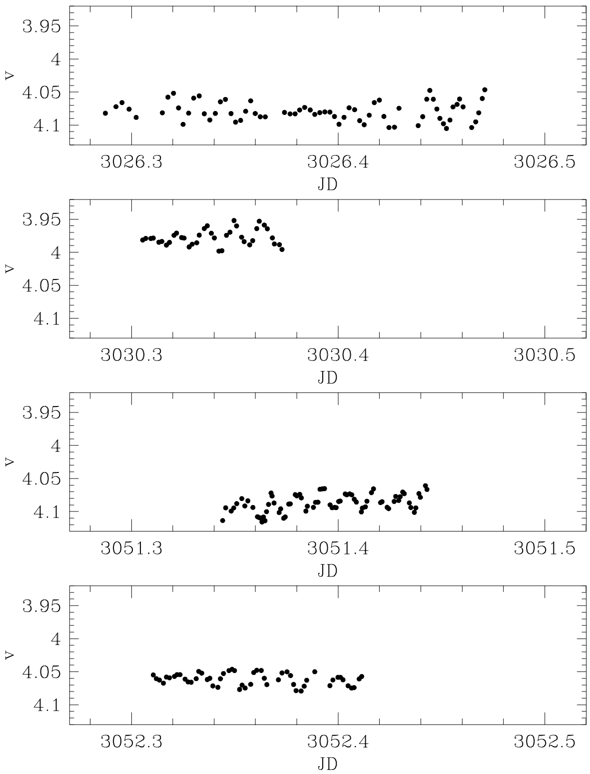

Figure 1. v light curves of the δ Sct PMS star HD 34282 during four nights in January and February 2004 (JD+2450000.00).

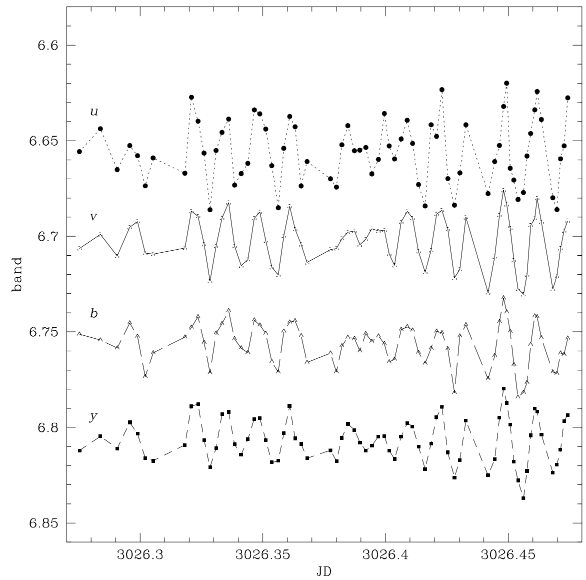

Figure 2. u, v, b and y band light curves of HD 34282 on the first night of observations. The mean values of the u and y light curves have been displaced for the sake of clarity.

already been undertaken at the Sierra Nevada Observatory (OSN), Spain, within the framework of a collaboration between the Observatoire de Paris and the Instituto de Astrofísica de Andalucía. Although still ongoing, this survey has already yielded a first important result in the discovery of four short-term variables, one of which is HD 34282.

HD 34282 (= V1366 Ori) has been classified in the spectral range between A0 and A3 by several authors (Gray & Corbally 1998; Mora et al. 2001; Merín et al. 2004). This is a very interesting object because: 1) the star has strong IR excess (Sylvester et al. 1996; Malfait et al. 1998; Merín et al. 2004), 2) it is a relatively nearby star, according to Hipparcos measurements $d = 160^{+60}_{-40}$ pc, (van den Ancker et al. 1998) and 3) observations with the IRAM 30m antenna revealed a double-peak profile in the $J = 2 \rightarrow 1$ transition of the CO molecule, characteristic of a large rotating disk, further supported by Plateau de Bure interferometer observations (Piétu et al. 2003).

2 DATA OBSERVATIONS AND REDUCTION

The star was observed during four nights in January-February 2004, producing a time baseline of 25 days. The observations were collected with the 0.9-m telescope at the OSN and the automatic six-channel Strömgren spectrophotometer (Nielsen 1983). Standard stars were also observed to transform to the standard system. The star was then monitored for around 4 hours on the first night, and for two hours on the remaining nights. Figure 1 shows the v light curves of HD 34282 for the four nights of our observations. The ranges of both axes have been fixed in order to show the number of hours of observations within one single day and the brightness variations of the star from day to day. The mean standard magnitudes and indices for HD 34282 are: $V = 9.873$, $(b - y) = 0.126$, $m_1 = 0.174$, $c_1 = 1.001$ and $\beta = 2.918$.

3 PHOTOMETRIC VARIABILITY

Long-term variations were reported by Malfait et al. (1998) who measured an optical variability of the order of 2.5 mag in the V band, which suggests that HD 34282 might be a UX Orionis star, i.e., a pre-main-sequence star, typically of intermediate mass, which is distinguished from other pre-main-sequence stars by its large photometric and polarimetric variations, thought to be due to variable extinction by CS dust. Our data for HD 34282 show photometric variations at two time scales: from day to day and within a day, as seen in Fig. 1. The day-to-day variations are not the main subject of the present work but rather the rapid intra-day variations. A blow-up of the data taken on the first night, where these intra-day variations are clearly visible, is shown in Fig. 2. The plot presents, from top to bottom, the u, v, b and y light curves, showing that the amplitude of the modulation decreases from the ultraviolet to the yellow bands.

In order to analyse these rapid variations avoiding interference with the day-to-day variations, the mean value for each day was removed. This average subtraction is actually a low frequency filtering which does not affect our analysis because the long-term variations only show significant power in the low frequency region of the Fourier spectrum up to 5 $\mathrm{c\,d^{-1}}$, very far from the rapid variation frequencies which fall in the region of 60-80 $\mathrm{c\,d^{-1}}$. The frequency analysis performed for the v-data, actually the best S/N band, is shown in Fig. 3. The procedure is similar to that presented in, e.g. Breger et al. (1994): pre-whitening of simultaneous

Table 1. Frequency in cycles per day, signal to noise, amplitude and its error and phase and its error for the two detected peaks in the Fourier spectrum of HD 34282.

	Frequency $\mathrm{c\,d^{-1}}$	S/N	Amp (mmag)	Error (mmag)	Phase (rad)	error (rad)
v band						
ν_1	79.5	19.4	10.7	0.6	0.2	0.1
ν_2	71.3	10.3	5.7	0.6	2.3	0.1
b band						
	79.5	20.3	8.2	0.6	0.4	0.1
	71.3	10.2	4.9	0.6	2.3	0.1
y band						
	79.5	14.6	8.2	0.6	0.4	0.1
	71.3	8.7	4.9	0.6	2.3	0.1

frequencies at each step until the S/N ratio decreases below 4. The last panel of Fig. 3 shows the Fourier transform of the differential v light curve of the comparison stars. The time span of these data is only of two days as compared to the 25-d baseline of the variable's observations, hence the different aspect of their Fourier spectra.

The final frequency solution for each photometric band is presented in Table 1. Frequency uncertainties remain a matter of controversy (see, for instance, Schwarzenberg-Czerny 1991) and the conservative rule-of-thumb given by Loumos & Deeming (1978) was chosen: 1.5/T, where T is our time baseline, yielding in our case 0.06 $\mathrm{c\,d^{-1}}$. The oscillation periods of this object are the shortest so far found for a δ Scuti variable. Particularly the highest frequency mode, with a period of only 18 min, can be considered as a new world-record for this type of pulsating star. Up to now, the two δ Sct variables with the shortest main periods known were the pulsating primary components in the semi-detached Algol-type eclipsing binaries RZ Cas (22 min, Rodríguez et al. 2004) and AS Eri (24 min, Mkrtichian et al. 2004). In both cases, the largest light curve amplitudes are observed in the u band as it seems to be the case for our star. This behaviour is explained as pulsation in a high radial order in stars near the blue edge of the instability strip as discussed in Rodríguez et al. (2004).

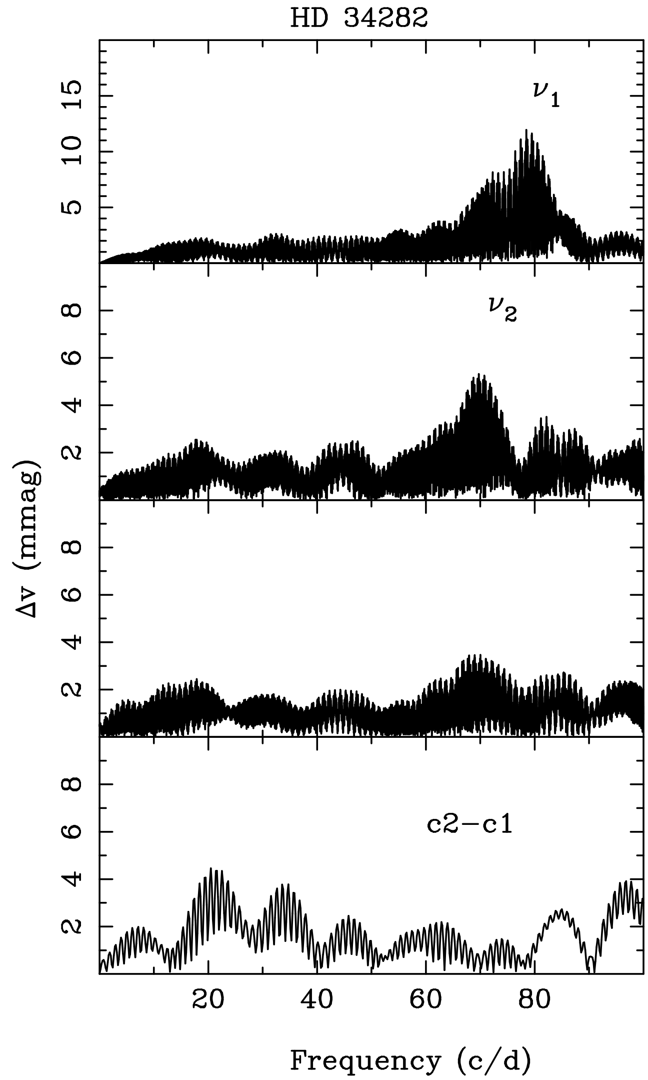

Figure 3. Fourier analysis of the v band Strömgren data. Results are given in Table 1. The Fourier transform of the differential photometry of the comparison stars (C2−C1) is given in the bottom panel

4 THEORETICAL MODELLING

The code TempLogG (Rogers 1995) was used to determine the physical parameters of the star from the standard Strömgren-Crawford indices derived for this work. The code classifies the star to be in the spectral-type region A0-A3 and the resulting physical parameters are $T_{\rm eff} = 8760$ K; $\log g = 4.4$. This is correct if its Strömgren indices are not 'contaminated' with non-standard photometric features coming from the surrounding material, such as line emission and/or filling-in of the Hβ line. However, the echelle spectra of Merín et al. (2004) show a CS contribution in this Balmer line among others, although not too large. These same authors give physical parameters for the star from high and medium resolution spectra: $T_{\rm eff} = 8625 \pm 200$ K, $\log g = 4.2 \pm 0.2$ and [Fe/H] $= -0.8 \pm 0.1$. These latter values were used to place the star in the HR diagram (see Fig. 4) and to produce theoretical stellar models. The solid symbol and the error box in this figure give the position and errors for HD 34282. The evolutionary tracks have been computed using the PMS models of the CESAM evolutionary code (Morel 1997). The straight thick lines represent the PMS instability strip from Marconi & Palla (1998) and, as it can be seen, the star falls outside and towards the hotter side of it.

Two different stellar models, one in the MS and another one at a PMS stage, with physical parameters given by the position of the star in the HR diagram, were computed using the CESAM code. The pulsational characteristics were calculated following the prescriptions given in Moya et al. (2004). The non-adiabatic oscillation code provides not only predictions of the unstable modes but also non-adiabatic quantities necessary to calculate phase differences and amplitude ratios which can then be compared with those derived from the observed Strömgren colour variations. The MS model predicts unstable radial and non-radial modes from 64.4 up to 81.4 $\mathrm{c\,d^{-1}}$ (corresponding to radial orders from $n = 6$ to 8), fitting fairly well the observed frequency range (from 69

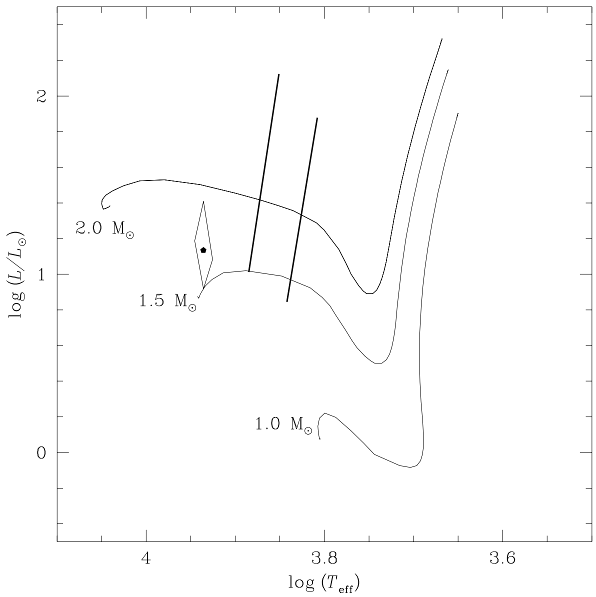

Figure 4. HR Diagram for the PMS star HD 34282. The solid symbol and the error box indicate the position of the star given by the physical parameters of Merín et al. (2004). The thick straight lines represent the PMS instability strip by Marconi & Palla (1998). The evolutionary tracks have been computed using the PMS models in the code CESAM.

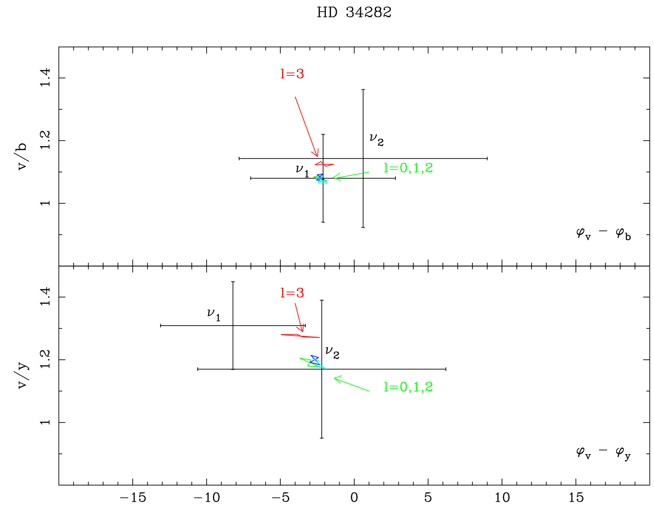

Figure 5. Phase/amplitude diagrams for the Strömgren v and b (top) and v and y (bottom) bands showing the different loci for various ℓ numbers. Large crosses are observed values with their error bars.

up to 80 $\mathrm{c\,d^{-1}}$). The PMS model predicts unstable modes in a very similar range, from 56.3 up to 82.2 $\mathrm{c\,d^{-1}}$, which also includes the observed periods. Therefore, from the point of view of the excited modes, both models are valid and no preference is deduced.

It must be said, however, that for the largest frequency to be unstable, the low metallicity found for this star by Merín et al. (2004) is essential. In the particular case of this star, a MS model with solar metallicity has a mass of 1.9 $\mathrm{M_\odot}$, whereas a model with [Fe/H] $= -0.8$, as derived from the aforementioned spectroscopic work, has a mass of 1.5 $\mathrm{M_\odot}$. The main consequence of this mass difference is the different range of unstable frequencies, particularly for the higher radial orders. The blue stability edge is found to be around the same radial order n in both cases, but for the solar metallicity model the highest excited frequency is around 850 μHz (73.4 $\mathrm{c\,d^{-1}}$) whereas, for the spectroscopically derived metallicity, it is slightly higher, around 950 μHz (82.1 $\mathrm{c\,d^{-1}}$) for the MS and 1030 μHz (89.0 $\mathrm{c\,d^{-1}}$) for the PMS one, being the observed frequency of 920 μHz (79.5 $\mathrm{c\,d^{-1}}$). For models with fixed $T_{\rm eff}$ and $\log g$ (the observational ones), the observed frequencies become excited only for models of lower mass, which can only be achieved by decreasing the metallicity.

The colour information provided by the Strömgren photometry enables a further comparison with theoretical models through the use of the phase differences and amplitude ratios between two photometric bands. As shown in Garrido et al. (1990), one of the best mode-discriminant indices is that formed by the pair $v-y$. Using the non-adiabatic quantities described in Moya et al. (2004) a phase-amplitude diagram can be constructed for the specific case of HD 34282 and it is displayed in Fig. 5. Unfortunately, the discrimination is not good for high order modes and high temperatures. With the large error bars derived for the present scarce observations, the oscillations are compatible with all possible non-radial and radial modes up to $\ell = 3$. Loci for different ℓ-values were calculated taking into account the uncertainties in effective temperature and surface gravity and the dependence of the non-adiabatic quantities with the oscillation period for both the MS and PMS models (see Moya et al. 2004, for a detailed explanation).

5 ROTATION

From the seismological point of view, rotational velocities of the order of, and even smaller than, that of HD 34282 ($v \sin i = 110 \pm 10$ $\mathrm{km\,s^{-1}}$, Merín et al. 2004) must be taken into account in both the stellar structure modelling and the oscillation computations for a correct interpretation of the observations (Saio 1981; Dziembowski & Goode 1992). Both aspects have been considered here and, particularly, the adiabatic oscillation frequencies are corrected for effects of rotation to second order, i.e. centrifugal and Coriolis forces (see Suárez et al. 2002, for a recent application). Models are computed for two rotational velocities (110 and 130 $\mathrm{km\,s^{-1}}$) and lying in the ranges 1.50–1.55 $\mathrm{M_\odot}$ and $\log T_{\rm eff} = [3.91, 3.95]$, i.e., within the photometric errors. From these models, it can be concluded that rotation does not significantly modify the range in which observed frequencies are found. Furthermore, this range corresponds to radial order $n = [6, 7]$, for $\ell = 0$, 1 and 2 modes, thus lying within the range of predicted unstable modes. These results must be interpreted carefully since the instability analysis does not take into account the effects of rotation.

6 CONCLUSION

A systematic search for short-term photometric variability has been undertaken for all known Herbig Ae stars with the goal of detecting their intrinsic variability and of precisely

locating them in the HR diagram, in order to constrain the position and size of the observed PMS instability strip. The work presented here for HD 34282 is one result of this search.

HD 34282 was found to pulsate at at least two frequencies. This is an important result in itself since it adds to the short list of PMS stars known to belong to the δ Scuti pulsators. Furthermore, the highest of its frequencies yields a period of only 18 min, which is the shortest found so far for this type of star. Moreover, the largest amplitude of the light curves in the Strömgren system is observed in the u band. This behaviour is explained as pulsation in a high radial order in stars near the blue edge of the instability strip.

The central star of HD 34282 is theoretically expected to pulsate whether it is a normal MS or a PMS star in the same position in the HR diagram. Furthermore, the highest of the observed frequencies only becomes unstable for models of low metallicity, pointing thus towards the same conclusion as that from spectroscopic measurements, that is, that the star is metal-poor.

More observations better distributed in time are needed to allow the detection of more periods and more precise phases and amplitudes, so permitting a better understanding of this object. This will give us a possibility of modelling the physical conditions of the deep interior of a PMS star.

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